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SHOCK PROPAGATION AND INSTABILITY STRUCTURES IN COMPRESSED SILICA AEROGELS

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Abstract

We have performed a series of experiments examining shock propagation in low density aerogels. High-pressure (~100 kbar) shock waves are produced by detonating high explosives. Radiography is used to obtain a time sequence imaging of the shocks as they enter and traverse the aerogel. We compress the aerogel by impinging shocks waves on either one or both sides of an aerogel slab. The shock wave initially transmitted to the aerogel is very narrow and flat, but disperses and curves as it propagates. Optical images of the shock front reveal the initial formation of a hot dense region that cools and evolves into a well-defined microstructure. Structures observed in the shock front are examined in the framework of hydrodynamic instabilities generated as the shock traverses the low-density aerogel. The primary features of shock propagation are compared to simulations, which also include modeling the detonation of the high explosive, with a 2-D Arbitrary Lagrange Eulerian hydrodynamics code The code includes a detailed thermochemical equation of state and rate law kinetics. We will present an analysis of the data from the time resolved imaging diagnostics and form a consistent picture of the shock transmission, propagation and instability structure.

Recently, there has been much interest in creating warm dense matter (WDM) in the laboratory and in characterizing the temperature, density and state of ionization of the matter. Warm dense matter is a state near and greater than solid density and with temperatures in the range from less than ~1 eV to a few eV. At these densities and temperatures, the atoms and molecules are becoming partially ionized due to pressure ionization, and the atomic and molecular electronic configurations are beginning to overlap. Any material that starts out from a cold state and becomes a true hot high-density plasma by laser heating, for example, must transition through the warm dense matter regime. The problem is that this regime is very poorly understood and presently not well described by any model or theory. Thus, in this case, detailed experiments are required to drive and motivate theory and model descriptions. We have found a way to create matter in this density-pressure regime for approximately 10 microseconds by having low-density aerogels compressed by colliding shocks from high explosives.

The goal of this work is two-fold. The first goal is to design a way to create WDM by using shocks waves from high explosives and the other objective is to test the recently developed ALE/Cheetah code[1] developed at LLNL. We use this code to model our experiments and to predict the region of phase space that we have achieved in the shock compression experiments. In order to create WDM, we have compressed low-density (100mg/cc to ~300 mg/cc) silica aerogel with single and colliding shocks from an HMX-based explosive (LX-10). Two configurations are shown schematically in Fig. 1. The single shock experiments were our first attempt to create WDM. We find that the single shock configuration is not very effective in producing WDM states. The aerogel becomes optically bright as the shock wave first enters the aerogel, but then quickly cools as it expands. An interesting residual microstructure appears after expansion and cooling. The understanding of this microstructure is still under investigation. In the case of the colliding shocks, a thin-hot region remains optically bright for tens of microseconds. These results are confirmed by our ALE/Cheetah calculations.

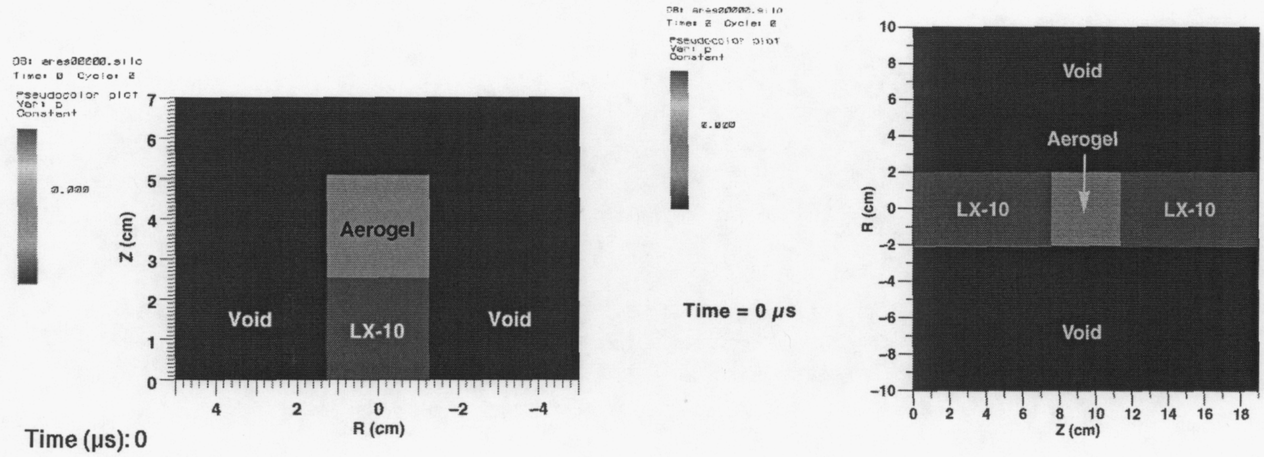


Figure 1. Schematics of the single and colliding shock compression of aerogel. For the case of the colliding shock experiment, the LX -10 is detonated simultaneously at both ends, so that the colliding shock from the high explosives meet at the center of the aerogel.

The diagnostics for these experiments are radiographic imaging and optical and radiance imaging. In the future we plan to use radiographic imaging to determine densities and spectral photometry to determine temperatures. We will look for neutral Si lines near 400 nm, which should be observable at thermal temperatures between 1 eV to 2 eV. With line emission modeling, one can extract a temperature based on line intensity ratios. In the case of the single-shocked aerogel, the data shows strong compression and emission as the shock is transmitted to the aerogel, with the pressure wave being transmitted to the aerogel being of order 50 kbars. Figure 2 is a comparison between the radiographic measurements and the pressure waves from our calculations. Within the high explosive we observe the well-know flat shock front. In the third frame, the radiographic image shows the show wave as it first transits the aerogel. This is followed by dispersion and a subsequent cooling and curvature of the shock as it propagates.

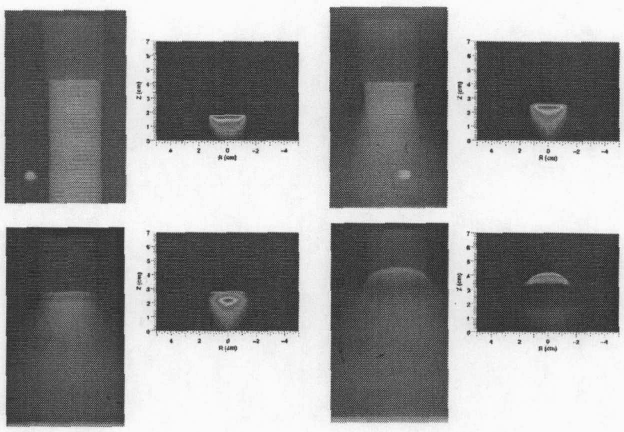


Figure 2 shows a comparison between radiographic measurements and calculated density pressure

Radiography is critical in understanding the nature of the transmitted shock wave in the aerogel and in validating hydrodynamics aspects for model comparison with ALE/Cheetah. The radiographic data has shown good agreement with the calculations, and we are presently working on a quantitative analysis comparison. These data on transmitted shocks and shock behavior in aerogel are a milestone in our fundamental understanding and reinforces out imaging data of the shock front as it develops. Fast imaging of the shock front revealed a steady reduction in emission (a cooling effect), which we now know from the radiographic data correlated to dispersion of the shock front. Observed structure is much larger than the cell structure of the aerogel. Although these structures are very apparent in the optical imaging, they are not discernable in the radiography.

To determine the limits of the WDM regime that can be explored with energetic materials, we have also used a colliding shock technique. Here, the silica aerogel is compressed with two planar shocks. These results show the creation of a hot disk of matter with calculated temperatures well over 1 eV. These temperatures are sustained for over 2 microseconds and strong radiant emission lasts over 20 microseconds. The peak pressure is calculated to be about 0.5 Mbar and the peak density to be over 10 g/cc. We have modeled these experiments with an ALE hydrodynamics code that includes a kinetic, thermo-chemical equation of state for fluids at high temperatures and pressures to model the detonation wave and a molecular disassociation model for the silica. Our silica model also replicates shock Hugoniot data from previous aerogel experiments. Figure 3 shows the optical and radiance imaging data from these experiments. The experiments clearly reveal the compression of the aerogel into a thin plate or ring.

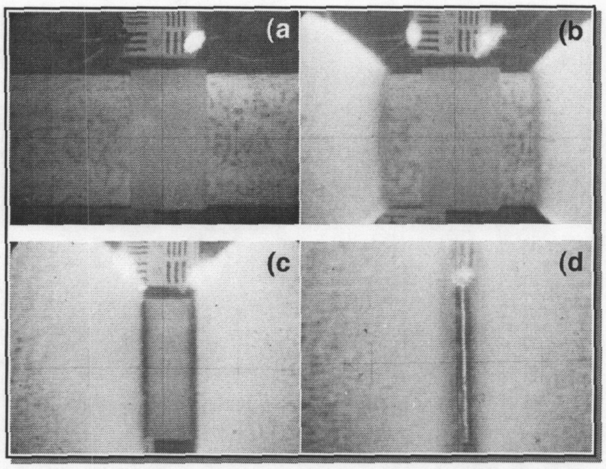
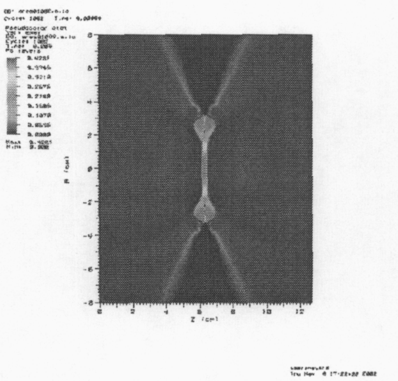


Figure3. Optical and radiance imaging time sequence of colliding shock wavers compressing low-density silica aerogel to over 10 g/cc. Exposure time per image is 0.42 microseconds and the peak pressure is over 0.5 kbar. Figure a) shows two solid cylinders of LX-10 with the aerogel sample between them at detonation time; b) 10 microseconds later the detonation is trundling through the LX-10 and approaching the aerogel: c) shows the shock front established in the aerogel and d) shows maximum compression the compressed aerogel starts to emit.

Figure 4 shows the calculated energy density (Mbar/rho) in the colliding-shock compressed aerogel at a time when the shocks first meet in the center of the aerogel and also at a time 10 microseconds later. The calculations show the development of a thin, relatively high-density, disk, surrounded by a low-density ring. The high-density in the disk is sustained for a few microseconds, before subsequent expansion.



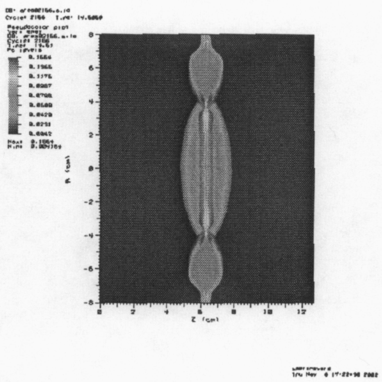


Figure 4. Calculated energy density (Mbar/rho) for the case of the colliding-shock compressed aerogel. The first frame shows the energy density when the shocks from the high explosive first meet in the center of the aerogel. The second frame is the energy density approximately 10 microseconds later, showing the development of a thin disk and low-density ring of high-emission matter.

We are making progress towards producing states of WDM by compressing low-density aerogels with colliding shocks. We have addressed WDM density/temperature regime via an aggressive series of experiments in shocked silica aerogels, correlated with calculations using a ALE/Cheetah code. Our experiments have focused on imaging/radiance measurements of the shock compressed aerogels in addition to detailed radiography to understand shock behavior. The next step in the calculations is to include the effect of pressure ionization in the equation of state. The next step in the experiments is to more precisely define the phase by determining the density from radiography and determining the temperature by photometry and neutral Si line emission..

References:

1. W. M. Howard, L. E. Fried, P. C. Souers and P. A. Vitello, "Calculations of Chemical Detonation Waves with Hydrodynamics and a Thermochemical Equation of State, APS Topical Conference on Shock Waves in Condensed Matter, Atlanta, Georgia, June, 2002.